N87-20925

COMPACT, VARIABLE, MOVING SOURCES OBSERVED ON THE SUN AT 2 CENTIMETERS WAVELENGTH

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INTRODUCTION

The high angular resolution provided by the Very Large Array (VLA) has permitted the spatial resolution of solar microwave sources and opened the way for comparisons with observations of similar angular resolution at optical and X-ray wavelengths. High-resolution VLA observations of solar active regions at relatively long wavelengths of 6 cm and 20 cm have, for example, led to the discovery of the microwave counterpart of the ubiquitous coronal loops that had previously only been observed by X-ray telescopes lofted above the Earth's atmosphere. The microwave emission of the coronal loops is attributed to the gyroresonant radiation and/or the bremsstrahlung of million-degree, thermal electrons trapped within the loops by strong magnetic fields; observations of this emission have provided valuable new insights into the nature of solar active regions and eruptions from the Sun and nearby stars [Kundu and Lang (1985); Lang (1986 a,b - this proceedings)].

In contrast, the short wavelength 2 cm emission of solar active regions is poorly understood. In spite of numerous VLA solar observations at 2 cm, there are only two published results [Lang, Willson and Gaizauskas (1983); Shevgaonkar and Kundu (1984)]. In both instances, compact (angular sizes $\theta \approx 15''$), highly polarized (degrees of circular polarization ρ_C = 80% to 90%) sources were found in regions of strong magnetic field (strength $H \approx 2{,}000$ G) above sunspots. The brightness temperatures of $T_B \approx 10^5$ K were characteristic of the electron temperature in the transition region.

Subsequent examination of the compact 2 cm sources in active regions indicated that they are variable over time scales of an hour or shorter. This probably explains the paucity of VLA results; synthesis maps averaged over 11 or 12 hours would not reveal several relatively-weak, time-variable sources.

To further complicate the matter, we have recently discovered compact, variable, highly-polarized 2 cm sources in regions of apparently-weak, photospheric magnetic field [Willson and Lang (1986)]. Our subsequent VLA observations have confirmed the existence of compact, variable 2 cm sources that are not associated with active regions, but these sources had no detectable circular polarization. In addition, both the unpolarized and polarized 2 cm sources were found to move laterally across the solar surface with velocities $V \approx 1$ km s^{-1}. In the next section we present observations of these compact, variable, moving sources. The concluding discussion mentions possible radiation mechanisms and implications for studies of the quiet Sun.

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OBSERVATIONS

The VLA was used to observe the active region AR 4508 in the C configuration between 1530 and 2330 UT on June 4, 1984. The position of this region was N06 E57 at 1300 UT on this day. Follow-up observations were made between 1500 and 2300 UT on January 17, 1986 in the D configuration. In this case, a region of bright plage and relatively-weak magnetic fields (no sunspots) was observed; its position was S10 W62 at 1300 UT on this day.

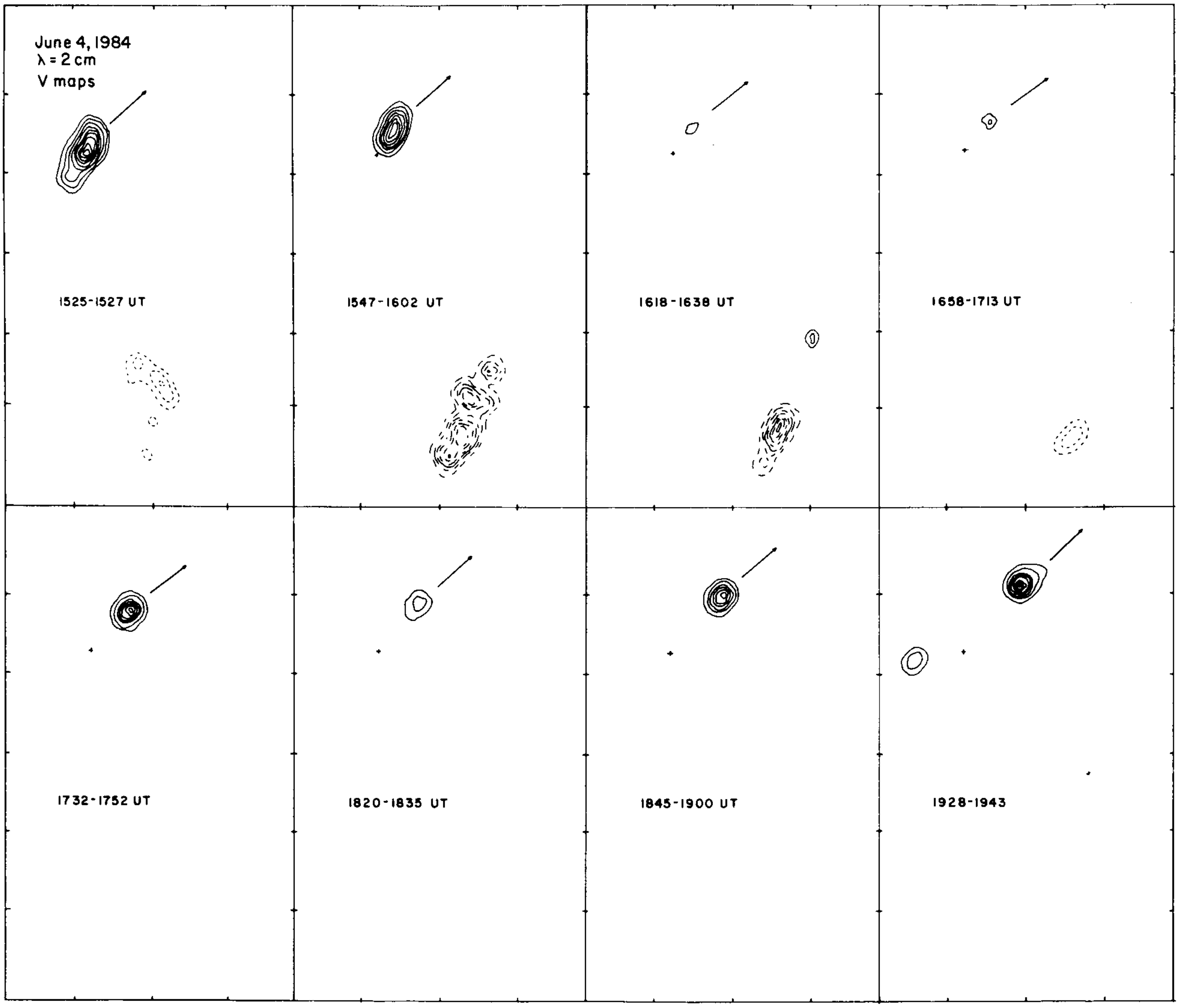

Figure 1. VLA synthesis maps of left circularly polarized (solid contours) and right circularly polarized (dashed contours) radiation at 2 cm wavelength. Here each box refers to the same area on the surface of the Sun, and the fiducial marks on the axes are separated by 10 arc-seconds. The northern source (top) varied over time scales of 30 minutes and moved laterally across the solar surface in the northwest direction a velocity of ~ 1 km s^{-1}. The southernmost source varied over a time scale of about 60 minutes, and moved laterally towards the southwest at a velocity of ~ 2 km s^{-1}. Here the contours mark levels of equal brightness with an outermost contour of 6.1×10^4 and a contour interval of 3.1×10^4 K.

As illustrated in Figure 1, the 2 cm maps on June 4 showed two compact ($\theta \approx 5''$), highly circularly polarized (ρ_C = 80 to 90%) sources that vary on time scales of 30 to 60 minutes. The left circularly polarized source (solid contours) varied in maximum brightness temperature from $T_B = 2.0 \times 10^5$ K to $T_B < 0.5 \times 10^5$ K. Here each box refers to the same area of the Sun, and the arrows illustrate systematic motion to the northwest with a total motion of about 15" in three hours. The left circularly polarized source was therefore moving laterally across the surface of the Sun with a velocity of $V \approx 1$ km s^{-1}. The right circularly polarized source (dashed contours) apparently moved towards the southwest at about twice this speed, but the motion is confused by the presence of more than one source.

Comparisons with Mt. Wilson magnetograms indicate that the two compact, variable, moving sources were located in regions of apprently-weak photospheric magnetic field (H < 80 G), and that they did not overlie sunspots. The high polarization of these sources is therefore somewhat enigmatic, for the polarization of thermal radiation requires strong magnetic fields of H $\approx$ 2,000 G. We will return to this paradox in the discussion.

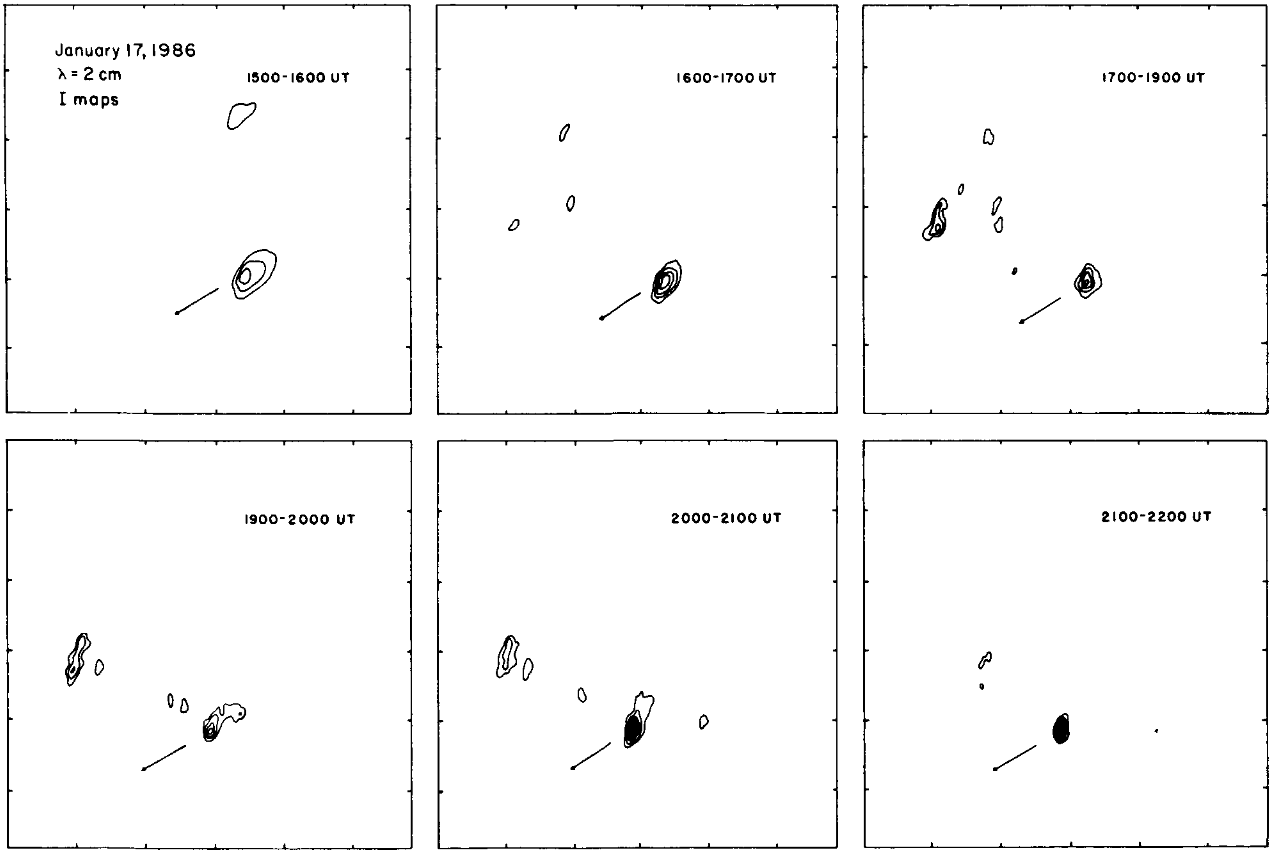

Figure 2. VLA synthesis map of the total intensity of the radiation at 2 cm wavelength. Here each box refers to the same area on the surface of the Sun, and the fiducial marks on the axes are separated by 60 arc-seconds. The southern source (bottom) increased slowly in brightness over a seven hour period while moving laterally across the solar surface in the southeast direction at a velocity of ~ 1 km s^{-1}. The northern source (top) varied over a time scale of 180 minutes, but showed no detectable lateral motion. Here the contours mark levels of equal brightness with an outermost contour of 5.2×10^4 K and a contour interval of 1.8×10^4 K.

Our confirming observations on January 17, 1986 revealed compact 2 cm sources with angular sizes $\theta \approx 25''$ and maximum brightness temperatures of $T_B = 2.0 \times 10^5$ K These sources were observed in plage regions with apparently-weak photospheric magnetic field and no sunspots, but in this case the compact sources had no detectable circular polarization ($\rho_C < 15\%$).

As illustrated in Figure 2, the compact unpolarized sources either varied substantially in intensity over time scales of hours (top sources) or slowly increased in brightness over a seven hour period (bottom source). Here each box refers to the same area on the surface of the Sun, and the arrows indicate a lateral motion at a velocity of $V \approx 1$ km s^{-1}. Curiously, the relatively-unvarying source exhibited this motion, but the variable one showed no detectable motion.

DISCUSSION

We have discovered previously-unobserved sources at 2 cm wavelength in regions of apparently-weak photospheric magnetic field. The brightness temperatures of $T_B \sim 10^5$ K are characteristic of the transition region. The angular sizes are $\theta \sim 5''$ to $25''$, and they vary in intensity over time-scales of 30 minutes to more than 180 minutes. We have observed at least two of these compact, variable 2-cm sources within the 3' field of view every time we have observed the Sun; extrapolating to the 30' - wide Sun, we would expect hundreds of them on the visible surface of the quiet Sun. The compact, variable sources can either be highly circularly polarized ($\rho_C \approx 90\%$) or they can exhibit no detectable circular polarization ($\rho_C < 15\%$).

The enigmatic presence of highly polarized sources in regions of apparently-weak photospheric magnetic field may be explained by any one of three hypothesis. First, the photospheric field may have strengths of up to 2,000 G in compact regions that are not readily detected by the photospheric magnetograms. Alternatively, the magnetic field in the transition region or the low corona may be amplified by currents to a strength above that in the underlying photosphere. If either of these hypothesis is true, then the high circular polarization of the 2 cm sources can be attributed to either thermal gyroradiation or the propagation of thermal bremsstrahlung in the presence of a magnetic field of strength $H \approx 2{,}000$ G. A third hypothesis, developed by Willson and Lang(1985), is that the compact 2 cm sources are due to nonthermal gyrosynchrotron radiation of mildly relativistic electrons in relatively weak magnetic fields of strength $H \approx 50$ G.

But what accounts for the variability and lateral motion of both the polarized and the unpolarized sources? The source variability might be due to a variable magnetic field that comes and goes within the transition region and low solar corona. Alternatively, the variations could be interpreted in terms of thermal electron density variations related to heating changes or to non-thermal electron density variations resulting from a variable acceleration mechanism. The lateral motion can be attributed to an upward expansion of dipolar loops; the 2-cm observations detect the apparent lateral motion of the loop legs.

Finally, we would like to point out certain resemblances between the compact, variable 2-cm sources and other phenomena reported in this proceeding. These sources are resolved (they are not points) with angular sizes comparable to those of small erupting filaments [Martin (1986 - this proceedings)] and the 20 cm observations of so-called coronal bright points [Habbal (1986 - this proceedings)]. The time scale of the variations and the lateral motions of the 2-cm sources are comparable to those of the small erupting filaments. The brightness temperatures of the 2-cm sources are the same as those of the 20-cm ones. Comparisons with features seem at the He I, λ 10830 transition are very misleading, for there are so many of these features that the statistical significance of a correlation has to be very low.

ACKNOWLEDGEMENTS

Radio astronomical studies of the Sun at Tufts University are supported under grant AFOSR-83-0019 with the Air Force Office of Scientific Research (AFOSR) and contract N0014-86-K-0068 with the Office of Naval Research (ONR).

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